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Local wind forcing of Korea/Tsushima Strait transport

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Abstract. The wind forcing and transport response in the synoptic frequency band (2-20 days) is examined through the Korea/Tsushima Strait. The lagged correlation of transport to wind stress indicates southerly wind stress across the both the Yellow Sea and Japan/East Sea is related increased transport. A linear barotropic adjoint model indicates more directly where and at what time lag the wind stress is most important in determining the strait transport. Results indicate that the southerly wind stress across the Japan/East Sea off the Korea coast is most important in forcing the transport through the strait. The wind stress across the Yellow Sea is not dynamically linked to the strait transport. The wind stress information is carried through Kelvin waves that propagate to the strait from the Japan/East Sea, but away from the strait in the Yellow Sea.

Introduction

The mechanism through which the wind stress is connected to the transport through the Korea/Tsushima strait depends on the time period of interest. The mean and seasonally varying transport are expected to be driven by the sea level drop across the strait. The large scale gyre circulation in the Pacific Ocean determines sea level at the entrance to the strait, and the Japan/East Sea (JES) determines the sea level at the exit. The transport through the Korea/Tsushima Strait has been observed through sea level variations across the strait (Yi, 1966), hydrography (Isobe, 1994), ship-board acoustic Doppler current profiler (ADCP) (Katoh, 1993), and moored instruments (Jacobs *et al.*, 2001), and these measurements are all in rough agreement on the mean and seasonal transport. However, the short time period variations and the connection to wind stress are not well known.

Mizuno *et al.* (1986) examine the correlation of one current meter mooring deployed between Tsushima Island and Japan to the simultaneous wind stress near the same point. Only a small portion of the current variability appear to be correlated to the wind stress at the same point. The wind stress across the Yellow and East China Seas forces large sea level changes (Hsueh, 1988, Jacobs *et al.*, 1998), and it would be expected that the sea level variations would force transport changes through the strait. Correlation of transport to wind stress indicates this mechanism as a possibility. However, a more detailed examination of the ocean physics through numerical models indicates that it is the wind stress across the JES off the Korea coast that is more important.

Numerical model

The numerical model employed is sigma coordinate model similar to the Princeton Ocean Model (POM) [Blumberg and Mellor, 1987]. The main difference between the present model and POM is that the time stepping of the external mode is provided through an implicit scheme. The external mode numerical stability is maintained even with much large time steps [Martin, 2000]. The model contains the Mellor-Yamada level 2.5 turbulence closure scheme [Mellor and Yamada, 1974]. The East Asian Seas (EAS) model covers the South China Sea through the JES at 1/8° horizontal resolution (Figure 1) so that boundary conditions do not exist at straits connecting the Asian marginal seas. Open boundary conditions are provided by a _° horizontal resolution model covering the Pacific north of 20°S with 26 sigma levels. Subsurface temperature and salinity are initialized from the Modular Ocean Data Assimilation System (MODAS) climatology. Both models are forced by wind stress and heat flux from the Navy Operational Global Atmospheric Prediction System (NOGAPS).

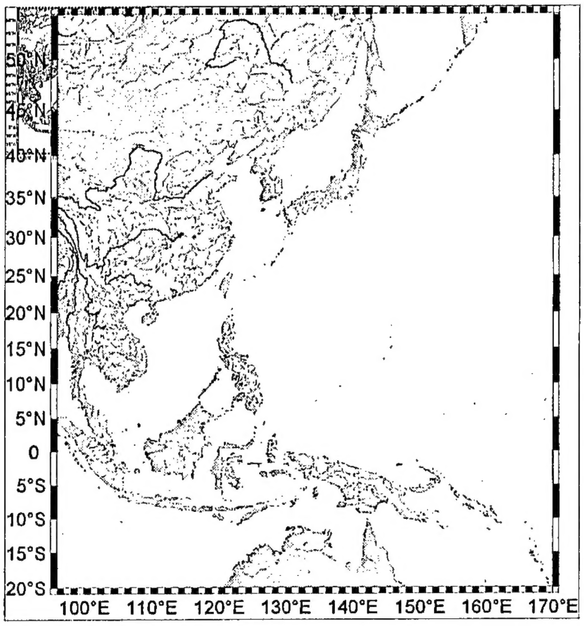

Figure 1. The numerical model is run at 1/8 degree resolution and forced by NOGAPS analysis wind stress.

The transport through the Korea Strait is computed from the model velocity and band-pass filtered using two Bartlett filters with first 0 power points at 2 days and 20 days (Figure 2). A time series of observed transport over the same time period is provided from acoustic Doppler current profilers (ADCPs) moored along a line spanning the strait southwest of Tsushima Island (Jacobs *et al.*, 2001). The transport time series has been filtered by the same method as the model transport.

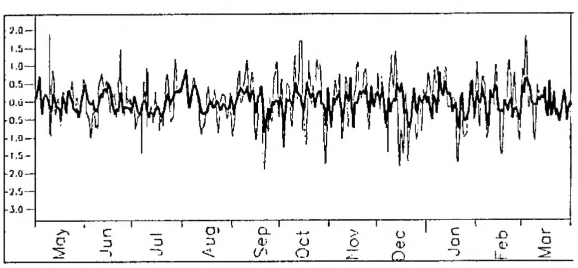

Figure 2. Transports filtered to the synoptic band (2-20 days) during 1999-2000 produced by the numerical model (thick line) and observed by current meters (thin line).

Correlation to wind stress

A first examination of possible mechanisms through which wind stress forces the strait transport is conducted by correlating wind stress to the transport. In this analysis the time-lagged covariance is computed between the transport times series and the time series of the wind stress components at each point in space. The covariance to the x wind stress and the covariance to the y wind stress may be plotted as a vector at each point (Figure 3).

A significance test is performed on each lagged cross-covariance by first computing the variance of the estimated cross covariance. The square root of this variance is used in Figure 3 to denote the significance. Cross covariance values less than the square root of the expected variance are not plotted, values less than 2 times the expected variance are plotted with thin lines, values less than 3 times the expected variance are plotted with medium lines, and values greater than 3 times the expected variance are plotted with thick lines.

The results indicate significant covariance of transport to wind stress in the Yellow Sea and the Japan/East Sea. The area over which the largest covariance occurs propagates southward with increasing time (from -2 day lag to 0 day lag). This is due to the typical atmospheric events that move through the region. These are frontal systems that create northerly wind bursts mainly during winter.

The difficulty in making definitive conclusions from the covariance analysis is the large scale nature of the atmospheric events. The spatial scales of features in the atmosphere are hundreds to thousands of kilometers. The wind stress at one point may be very influential to the strait transport, and the covariance is large at this point. However, second nearby point may not be influential to the transport, but the wind stress at this second may be very similar to the first point. The result will be that the covariance to the second point will be large even though the wind stress at the second point is not dynamically connected to the transport through the strait.

This effect is evident in the covariance analysis as wind stress over the Asian continent is significantly related to the transport through the strait. We would be hard pressed to define a physical mechanism through which the wind stress acting on the Asian land mass would force transport through the strait on synoptic time scales.

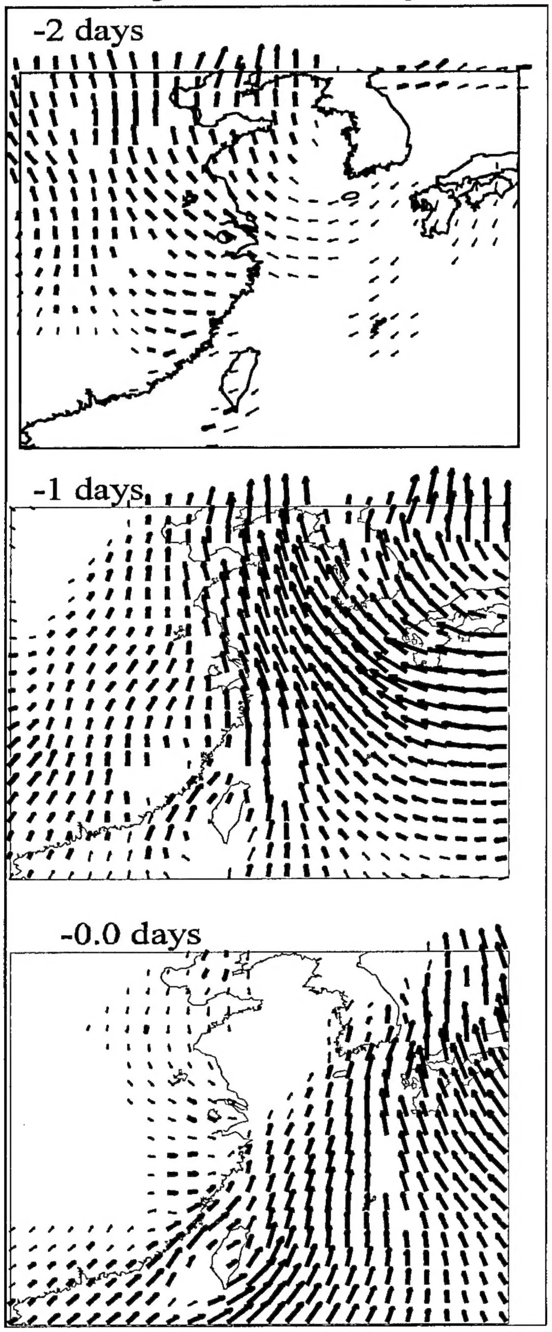

Figure 3. The model transport and wind stress cross covariance at several time lags (negative lag indicates that wind stress leads the transport). Thickness of the vectors indicates significance. The covariance indicates that the winds across either the Yellow Sea or the Japan/East Sea force the transport through the strait.

Adjoint analysis

The model could be used to determine the areas at which wind stress is most influential. By providing a small perturbation to the wind stress at a single point, the effect on transport could be gauged. However, this would require running the model once for every point at which wind stress is applied. This would be computationally unfeasible. Another method to derive the same information is through an adjoint model. The adjoint model provides a method to derive the derivative of a quantity that depends on the model with respect to the model inputs such as wind stress. The quantity of interest here is the transport through the strait, which is a linear functional of the model state.

A single adjoint run provides the sensitivity of strait transport to wind stress for all time lags and for all points in space. The adjoint model used here contains linear barotropic dynamics, which are greatly simplified relative to the forward model. However, the adjoint model indicates that the wind stress over the Yellow Sea is not greatly influential (Figure 4).

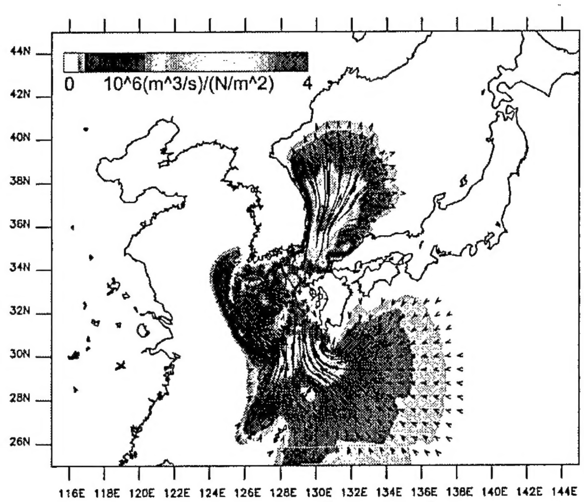

Figure 4. The results from the adjoint model experiment provide the derivative of the strait transport with respect to the wind stress over all time and space. The color shading indicates the amplitude of the derivative, and the vectors indicate the direction. This is at a time lag of -3 hours.

The wind stress across the Japan/East Sea off the coast of Korea is the most influential forcing for the strait transport. Wind stress south of the strait also contributes to the transport.

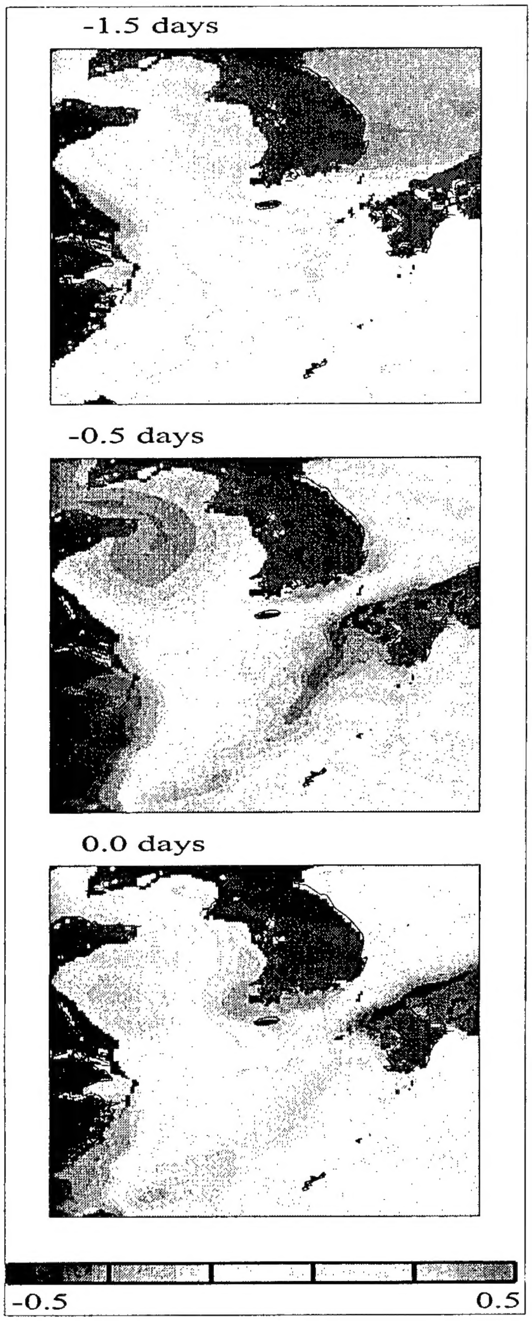

Figure 5. Correlation of the sea level to the transport in the East Asian Seas model indicates that a sea level setdown in the Japan/East Sea propagates through the strait. The cross-strait pressure gradient produces a geostrophic transport anomaly.

The reason that wind stress across the Japan/East Sea is much more influential than wind stress across the Yellow Sea is due to the propagation of Kelvin waves. A southerly wind stress produces a setdown along the eastern Korea coast and a setup along the western Korea coast. These sea level anomalies propagate as Kelvin waves. The Japan/East Sea setdown propagates to the strait while the Yellow Sea setup propagates away from the strait (Figure 5).

Conclusions

On time scales of 2-20 days the transport through the Korea/Tsushima Strait is forced by wind stress predominantly over the Japan/East Sea off the coast of Korea. A southerly wind stress initially causes a sea level setdown that propagates to the strait and produces a transport anomaly through the strait in near geostrophic balance.

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References

Blumberg, A., and G. Mellor, A description of a three-dimensional coastal ocean circulation model, in Three-Dimensional Coastal Ocean Models, *Coastal Estuarine Sci., vol. 4*, edited by N.S. Heaps, pp. 1-16, AGU, Washington, D.C., 1987.

Hsueh, Y., Recent current observations in the eastern Yellow Sea, *J. Geophys. Res., 93,* 6875-6884, 1988.

Isobe, A., Seasonal variability of the barotropic and baroclinic motion in the Tsushima-Korea Strait, *J. Oceanogr., 50*, 223-238, 1994.

Jacobs, G. A., H. T. Perkins, W. J. Teague, and P. J. Hogan, Summer transport through the Tsushima-Korea Strait, J. Geophys. Res., 106, 6917-6930, 2001.

Jacobs, G. A., W. J. Teague, S. K. Riedlinger, R. H. Preller, and J. P. Blaha, Sea surface height variations in the Yellow and East China Seas, 2, SSH variability in the weekly and semiweekly bands, *J. Geophys. Res., 103*, 18,479-18,496, 1998.

Katoh, O., Detailed current structures in the eastern channel of the Tsushima Strait in summer, *J. Oceanogr., 49*, 17-30, 1993.

Martin, P. J., Description of the Navy Coastal Ocean Model Version 1.0, *Naval Research Laboratory report NRL/FR/7322—00-9962*, 42 pp.

Mellor, G. L., and T. Yamada, A hierarchy of turbulence closure models for planetary boundary layers, *J. Atmos. Sci., 31*, 1791-1806, 1974.

Yi, S. U., Seasonal and secular variations of the water volume transport across the Korea Strait, *J. Oceanogr. Soc. Korea, 12*, 7-13, 1966.